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Knowledge, energy sustainability, and vulnerability in the demographics of smart home technology diffusion

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ABSTRACT

In this empirical study, we explore the user acceptance of smart home technologies by asking: How do people perceive their opportunities and drawbacks? What factors shape their perceptions? What implications does this have for future energy savings, sustainability, and policy? Based on a mixed methods approach involving three focus groups (N = 18) and a nationally representative survey of adults (N = 1032) in the United Kingdom, we explore the demographics, preferences, and risks of smart home technology. We do this via the lenses of knowledge and adoption; energy and climate sustainability; and vulnerability and exclusion. We explore how different classes of people—adopters versus non-adopters, high-income versus low-income, women and men, old versus young—support or oppose smart home technologies, have different degrees of knowledge and misperceptions, and reveal very different perceptions about the practices enabled by smart homes. In doing so, we show at times compelling links between smart homes and energy consumption, and possible negative impacts to poverty, inclusion, and empowerment.

1. Introduction

Human civilization is on the cusp of a possible new era of digital transformation, where people, and their homes and vehicles, have the possibility to remain constantly connected to a multitude of different smart technological devices. This interconnected, digital society has the potential to transform many aspects of our daily lives, including how we work (Allen 2017), and how we are monitored, surveilled, and tracked (Anthes, 2017; Han, 2020); even how we process information, seek entertainment, and play (Court and Sorrell 2020). Such changes can deeply shape activities in the home and domestic life, with an array of "smart" home devices, technologies, and systems available on the global market (Hargreaves and Wilson, 2017; Sovacool and Furszyfer Del Rio, 2020). As the Royal Academy of Engineering (2018: 1) put it optimistically, "Digital technologies … offer enticing possibilities for the future. We look forward to a world of seamless transactions and smart houses, with economic benefits for all."

However, the scale, scope, and distribution of these benefits is not predetermined, nor is the shift to smart homes and systems uniformly net beneficial for all. The International Energy Agency (2017: iv) noted this point explicitly when they stated:

Digital technologies are everywhere, affecting the way we live, work, travel and play. Digitalization is helping improve the safety, productivity, accessibility and sustainability of energy systems around the world. But it is also raising new security and privacy risks, while disrupting markets, businesses and workers.

In the extreme, Kendall-Taylor et al. (2020) caution that a digital, smart era can also empower authoritarian regimes (who are better able to track their citizens, co-opt critics and preempt protest and dissent). These regimes are, in their words, embracing smart systems and technology "to refashion authoritarianism for the modern age" which can lead to "durable digital autocracies," "digital repression," and in some situations, real violence and repression via torture or murder. For example, Han (2020) notes how digital authoritarianism and infrastructure for surveillance have become even more prominent during the recent COVID-19 pandemic. As the process of digitization and informatization advances, new modes of domination and control become possible alongside avenues of empowerment and autonomy (Luke, 1990; Pilkington, 2019a).

One aspect of change where the diffusion of smart home technologies (SHTs) hold great promise, but also potential peril, concerns sustainability, energy consumption, and climate change, the topic of this study.

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Building on an earlier study from Wilson et al. (2017), we explore the user acceptance of SHTs by asking: How do people perceive the opportunities and drawbacks of smart homes? What factors shape their perceptions? What implications does this have for future energy savings, sustainability, and policy? Based on a mixed methods approach involving three focus groups (N = 18) and a nationally representative survey (N = 1032) in the United Kingdom, we explore the demographics, preferences, and risks of SHTs via the lenses of knowledge and adoption; energy and climate sustainability; and vulnerability and exclusion. We explore how different classes of people—adopters versus non-adopters, high-income versus low-income, women and men, elder versus young—support or oppose SHTs, have different degrees of knowledge and misperceptions, and reveal very different perceptions about the practices enabled by smart homes, their links to energy consumption, and possible negative impacts to poverty, inclusion, and empowerment.

In proceeding on this path, the primary goal of the study is to achieve empirical novelty—presenting all data from our survey, rather than only the most statistically relevant results, or those relevant to some theoretical framework—rather than conceptual or methodological novelty (Sovacool et al., 2018). This is for four core reasons. First, our survey design benefitted from, and built on, Wilson et al. (2017), who, like us, had no deductive conceptual framework or theoretical approach. Second, the project funding our research also had empirical aims and objectives—it promised empirical deliverables, rather than conceptual or methodological ones. Third, we present the full empirical results of our survey in the hopes that others will continue to build on them, which means we give readers a cornucopia of data and let them decide which future avenues they may want to explore, or what they find interesting, rather than predetermining that for them or narrowing our focus to exclude data. Fourth and lastly, we wanted to be transparent in our analysis and avoid questionable behavior. Rather than "back fit" our results around only the most interesting or significant findings, a form of questionable data manipulation known as Hypothesizing After the Results are Known (HARKing) or retrofitting hypotheses to data in order to achieve higher significance (Hall and Martin 2019), we instead present all data across all of our findings, something considered better practice in the research community.

2. Smart home technologies in an era of global digitalization

This section of the study defines smart home technologies, summarizes literature on how they connect with energy consumption, and also discusses emergent risks.

2.1. Defining smart home technologies

There is a plethora of definitions of what SHTs are or what they can accomplish. Indeed, Sovacool and Furszyfer Del Rio (2020) summarize 10 definitions of smart homes, from the integration of different services within a home environment to a broader ensemble of technologies that provide tailored services for users.

Among the most prominent examples of SHTs are smart speakers Amazon Alexa and Echo[a] and Google Home[b] whose virtual assistants feature voice-controlled services such as streaming music, searching the internet, ordering products and checking the weather. Nest sells automated and digital thermostats, indoor and outdoor security cameras, smoke and carbon monoxide alarm, security systems, energy monitors, and video systems.[c] Hue is a product line of smart lights, lamps, lighting and blubs.[d]

What previous research suggests, however, is that SHTs must possess the ability to digitally connect to different devices and information sources in order to provide users with more customized services (Furszyfer Del Rio et al., 2020). Based on this, SHTs ought to have the potential to impact domestic life via the provision of feedback on personal health, to enhancing energy demand and control, and even to guaranteeing household safety and user wellbeing.

Complicating matters further, SHTs are not only confined to the bricks and mortar of homes, but also link them to the outside world through remote controlling and connections to cloud based services. Fig. 1, an example of "Society 5.0 in Japan", demonstrates how different parts of a digital society, including Internet of Things (IoT), Big Data, AI and automation using robots, interconnect into a "digital revolution". In the IoT, technologies and services, such as cloud computing services, social networks and SHTs, collect and share data on how devices are used and in which environments.

Automation and robots, on the other hand, are expected to replace many previously manual tasks. This kind of digital revolution will create societal changes that may be wide-reaching, profound and potentially long-lasting, entering also our domestic spaces. In the UK, an investigation conducted by The Guardian (2019), for example, reveals how millions of pounds are being spent developing a new generation of welfare robots to replace humans, and this process has generated a whole new jargon such as "virtual workforce", "augmented decision-making" and "robot process automation" to name a few. As a result, fears are growing that the human element of the welfare state is being diminished and as a consequence, discrimination and inequality against those who are less technology literate, or have no internet access, will likely worsen.

2.2. Smart home technologies and energy consumption

Within the burgeoning SHTs literature, much of the contents focus on notions of enhanced monitoring functions and control functionality of homes (Strengers and Nicholls, 2017; Wilson et al., 2017). SHTs are also becoming an integral part of modernizing the electricity grid and allowing new business models to prosper in a connected society (Furszyfer Del Rio et al., 2020).

Armstrong and colleagues, for instance, argue that the deployment of SHTs provides new opportunities for energy users to engage in more efficient energy practices at home (Armstrong et al., 2016). For instance, smart home energy technologies promise to learn and automate user behaviours and routines to make them more efficient (Sovacool and Furszyfer Del Rio, 2020). They also deliver feedback to improve user energy choices (Darby, 2018) and in consequence, aim to reduce energy consumption (Balta-Ozkan et al., 2014; Marikyan et al., 2019).

The deployment of smart home technologies is thus viewed by some as an essential element to transition towards a low-carbon economy. Technologies that allow energy services, such as enhanced demand management, are paving the way to enable smart charging of electric vehicles (Parag and Sovacool, 2016), shifting cooling and heating cycles and are permitting users to schedule their appliances to avoid peak loads (Davis et al., 2018). Better control and monitoring of home energy consumption can provide more comfortable homes through better energy management but could also lead to rebound effects whereby new energy savings are then spent elsewhere (Walzberg et al., 2020; IEA, 2017). Nicholls et al. (2020) suggest that the use of smart lights can lead to increments in energy consumption by encouraging the extra use of lighting for security, ambience and entertainment reasons. Strengers

[a] Amazon Alexa and Echo: https://www.amazon.co.uk/Echo-and-Alexa-Devices/b?ie=UTF8&node=10983873031 [Accessed 02.04.2020].

[b] Google Nest: https://store.google.com/gb/category/connected_home?hl=en-GB&GoogleNest&utm_source=nest_redirect&utm_medium=google_oo&utm_campaign=GS102776&utm_term=control [Accessed 02.04.2020].

[c] Nest: https://nest.com/uk/[Accessed 02.04.2020].

[d] Hue: https://www2.meethue.com/en-gb/smart-home-automation-light [Accessed 02.04.2020].

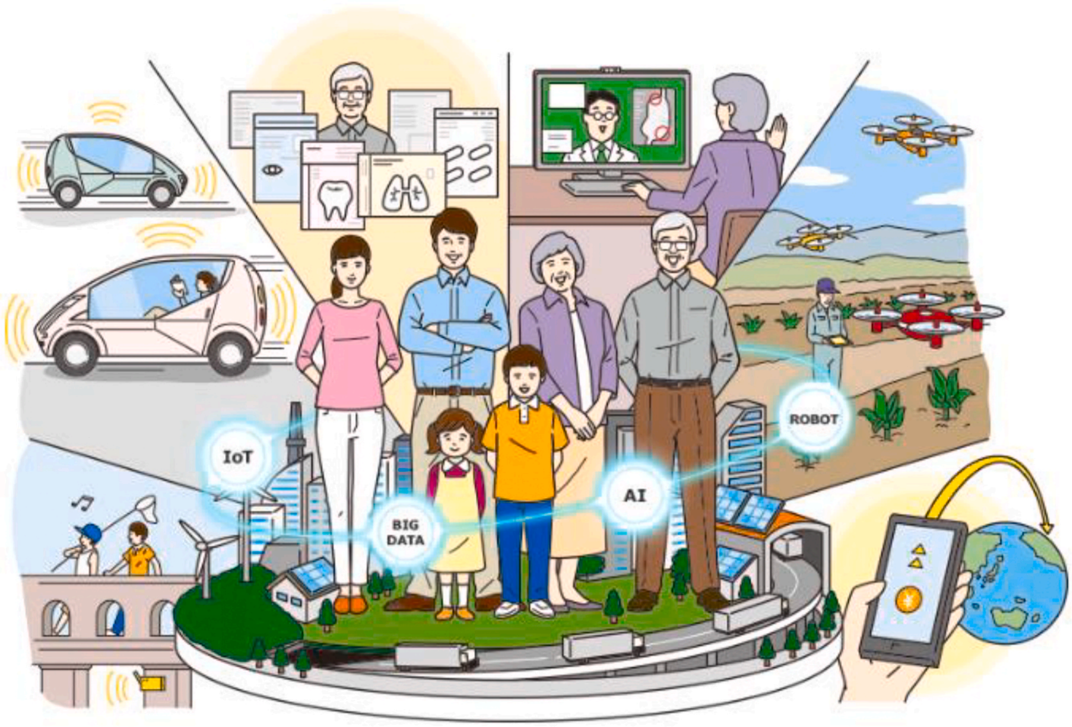

Fig. 1. The Government of Japan's Society 5.0 envisions a society of the future that is increasingly interconnected, automated, and smart.
Source: Government of Japan. (Cabinet Office Government of Japan, 2019).

et al. (2020) found in a review of consumer news and trade articles that SHTs had often been glorified as providing a better quality of life, yet not necessarily doing so in a sustainable manner.

However, although demand response technologies seem rather promising in delivering a broad range of flexibility services, the global capacity of all forms of demand-side flexibility grew by only 5% year-on-year in 2019, which is ten times lower than expected (IEA, 2020). Parrish et al. (2020) indicate that apathy towards services and devices that enable better energy management will persist unless the following issues are addressed; difficulty to set-up technologies, risk of losing control and loss of autonomy.

The transition towards a smarter energy system should also deliver outcomes beyond energy savings. Research has, for example, suggested that the deployment of information communication technologies (ICT) could make cities more resilient to climate impacts risks by swiftly recovering the grid from extreme events (Das et al., 2020) and lead to a more active society willing to participate in urban politics and governance (Houston and Gabrys, 2019), as long as digital skills are developed and nurtured.

However, the sustainability around smart homes has been contested from different angles. For instance, research notes how unsustainable these technologies are not only in issues related to human labour but also, regarding the extraction of rare materials and their effects over the environment (Crawford and Joler, 2018; Sovacool et al., 2020). To this, Williams (2011) adds that managing the direct impacts of ICTs in the energy system is more complex than just manufacturing efficient devices, and and for these technologies to be truly sustainable, one must consider the energetically expensive manufacturing process and the growing production of devices. Indeed, Hittinger and Jaramillo (2019: 319) note that the rapid increase in the number of smart connected products being deployed "may lead to an overall increase in energy use for material extraction, material processing, and component manufacturing."

Another area that questions the sustainability of the digital revolution is that related to the increments in data storage and the constant exchange of information online (Furszyfer Del Rio et al., 2020). A recent study by a global network company estimated that there will be 3.6 networked devices per capita by 2023, equivalent to around 29.3 billion products (Cisco, 2020). With this in mind, electricity consumption resulting from the information and communication sector is predicted to represent around 11% of the global electricity consumption in 2020 (Andrae and Edler, 2015). Furthermore, evidence indicates that electricity use by data centres globally in 2020 could be higher than the total electricity generated in the United Kingdom in 2017, and that the "global use of electricity by ICT devices in 2020 (such as mobile phones, computers and smart televisions) may be comparable to electricity generated by Japan in 2017" (Puebla et al., 2020).

2.3. Potential risks from smart home technologies

Thus, the installation of SHTs does not come without potential social risks. These can include lack of digital skills, lack of control, vulnerability, social exclusion, and threats linked to an increasingly digitalized society.

Living in a smart home requires some technical savviness and skills, and also financial investment in technology (de Souza Dutra et al., 2020), which may leave people on low incomes unable to participate in the digital society in the same way as their wealthier counterparts. In the United States, Pew Research Center (2019) noted that four-in-ten adults do not have broadband services when their incomes earn below $30,000 a year, meaning that 40% of this already vulnerable group has been left behind in the digital revolution. In the UK, meanwhile, almost 12 million people, or one in five of the population, do not have essential digital skills needed for modern day-to-day life (Pilkington, 2019b). The UK Consumer Digital Index 2019 showed that 4.1 million adults in the UK had not yet connected to the internet, while 11.9 million people did not have the required digital skills for everyday life, which included skills like the ability to manage money online, look for a job online or access government services online (Lloyds Bank 2019). These vulnerabilities related to income and poverty are also highlighted in a recent report by the United Nations Human Rights Office of the High Commissioner (2019) when they note that government decisions to "go digital" have been taken without significant discussions taking place over ethnicity, class, gender, and income.

SHTs could lead to situations where the control of the home could shift to the most tech savvy user, creating, in consequence, power imbalances within household dynamics (Freed et al., 2018; Nicholls et al., 2020; ITU 2016). There is also risk of SHTs leading to conflict within households, given that most of the systems are controlled through mobile phones, which makes interactions highly individualistic (Lucero et al., 2006). This can clash with family routines and dynamics that feature homes as a social environment inhabited by families, housemates or couples that need to cooperate rather than compete (Niemantsverdriet et al., 2017).

SHTs can also intersect with issues of vulnerability or dependence. SHTs can be beneficial in terms of assisting with care for those who may be forced to spend long periods of time at home, such as the elderly or people with long-term health issues. However, concerns such as data security, who has access to SHT data (Véliz and Grunewald, 2018) and potential hacking risks (Zimmerman et al., 2020), could jeopardize those who are less digitally literate. Additionally, vulnerable groups are not only represented by elderly people. Certain groups of women, for example, are disproportionately targeted by ICT-facilitated abuse. Such groups include women and girls with disabilities, belonging to ethnic minorities and/or other marginalized groups (Office of the United Nations High Commissioner for Human Rights, 2018). These groups of women are also often less digitally literate, making them even more vulnerable (West et al., 2019). Women's vulnerability to smart technologies could be represented by phishing[e] schemes common in the digital world (Lin et al., 2019; Poster, 2018) or being unaware when technology is being used by men to control them (Dimond et al., 2011).

In our research, we are particularly interested in how SHTs could be used in aiding sustainability goals such as reducing home energy use, and whether there are particular concerns linked to such devices in relation to potential vulnerabilities such as being of older age or living on a lower income.

3. Mixed methods research design

To explore these themes in SHTs, our sources of primary data for the study were twofold: a nationally representative survey (with quantitative and qualitative questions) distributed in the United Kingdom, alongside three public focus groups.

Our survey instrument, offered in Appendix I, built off earlier work examining user perceptions of smart homes conducted by Hargreaves et al. (2017) and Wilson et al. (2015, 2017). It was designed to take 10–15 min to complete, and it consisted of twenty questions across four sections. The first section explored the socioeconomic and demographic attributes of respondents. The second section investigated adoption patterns and knowledge of SHTs. The third section examined preferences in the technology as well perceived risks. The fourth had open-ended questions asking respondents to share experiences about SHTs as well as their willingness to be contacted for future research. Most questions used a 5-point Likert Scale (1 = strongly disagree, 5 = strongly agree), with the survey implemented online by a market research company, Dynata, using a respondent panel representative of the UK household population (homeowners and those who rent). Dynata scripted an online version of the survey instrument using their proprietary software. Once checked by the research team, Dynata sent unique person-specific links to the survey to individuals in their respondent panel who have agreed previously to take part in survey research in exchange for incentives. The sampling frame consisted of householders, in the UK, who had to be over the age of at least 18 years old.

A total of 166 respondents were screened out based on quality checks. These quality checks included "flat-liners," straight-line responses on blocks of questions; "rushers," those who gave incomplete, contradictory or unrealistic responses (e.g., the respondent who claimed to have 99 children); and "speeders," those who had unrealistically fast survey completion times. The final sample comprised 1032 respondents and these still provided a representative sample of the UK population. Fig. 2 shows some of the demographic details of our final sample, which were ensured to be nationally representative for gender, age, income, and region.

To triangulate the findings from the survey, we also conducted three focus groups in the last quarter of 2019 across London (n = 7), Greater Manchester (n = 4), and Surrey (n = 7). This included two urban locations (London and Manchester) and one rural one (Surrey). The Focus Groups were organized and managed by a separate market research company, YouGov. The focus groups lasted 90 min each, and involved a mix of different demographic respondents with the details summarized in Table 1. Participants were offered light food and refreshments during the focus group, and a £40 per person incentive to take part. The focus groups followed a similar structure to the survey, examining general knowledge of SHTs, experience and usage patterns, perceived benefits and disadvantages, trust, and values. Even though they were facilitated, recorded and fully transcribed by YouGov, at least one member of the research team observed all of the focus groups.

We analyzed our data using IBM SPSS Statistics software to produce descriptive statistics on our quantitative survey data, which was supported by inductive thematic analysis of the qualitative data from focus groups and the survey. We therefore conducted a more exploratory and inductive study, rather than set out to test any particular hypothesis (even though we were guided by previous research on this topic, in particular by Hargreaves et al. (2017) and Wilson et al. (2015, 2017)). To ensure anonymity, focus group participants are referred to in our results as follows: London male (LM), London female (LF); Manchester male (MM), Manchester female (MF); Surrey male (SM) and Surrey female (SF). The survey respondents are reported as a general respondent number (e.g. XX, XXX). For data analysis, we relied on a mix of Mann Whitney U non-parametric tests (this was used to compare two independent groups and is appropriate to use for ordinal variables e.g. Likert scale items) as well as Chi square tests (which is appropriate for testing binary variables) along with the more standard tests for significance and effect sizes (following guidance in Field, 2018; also Nachar, 2008). Benjamini -Hochberg Procedure was used as a post-hoc test to control for false positives (e.g. Thissen et al., 2016). Effect sizes were calculated using Cohen *d* (Cohen, 1988) for the Mann Whitney U tests, and Cramer's V for the Chi Square tests. To clarify, for Cramer's V:

- $V = 0$, variables are not associated;
- $V < 0.25$, association is weak;
- $0.25 < V < 0.75$, association is moderate;
- $V > 0.75$, association is strong;
- $V = 1$, association is perfect

And, for Cohen's d:

- $d < 0.20$ 'trivial' effect size;
- $d = 0.20$ small effect size;
- $d = 0.50$ medium effect size;
- $d = 0.80$ large effect size.

Detailed results of both post-hoc tests and effect sizes are reported in Appendix II.

[e] The fraudulent practice of sending emails purporting to be from reputable companies in order to induce individuals to reveal personal information, such as passwords and credit card numbers.

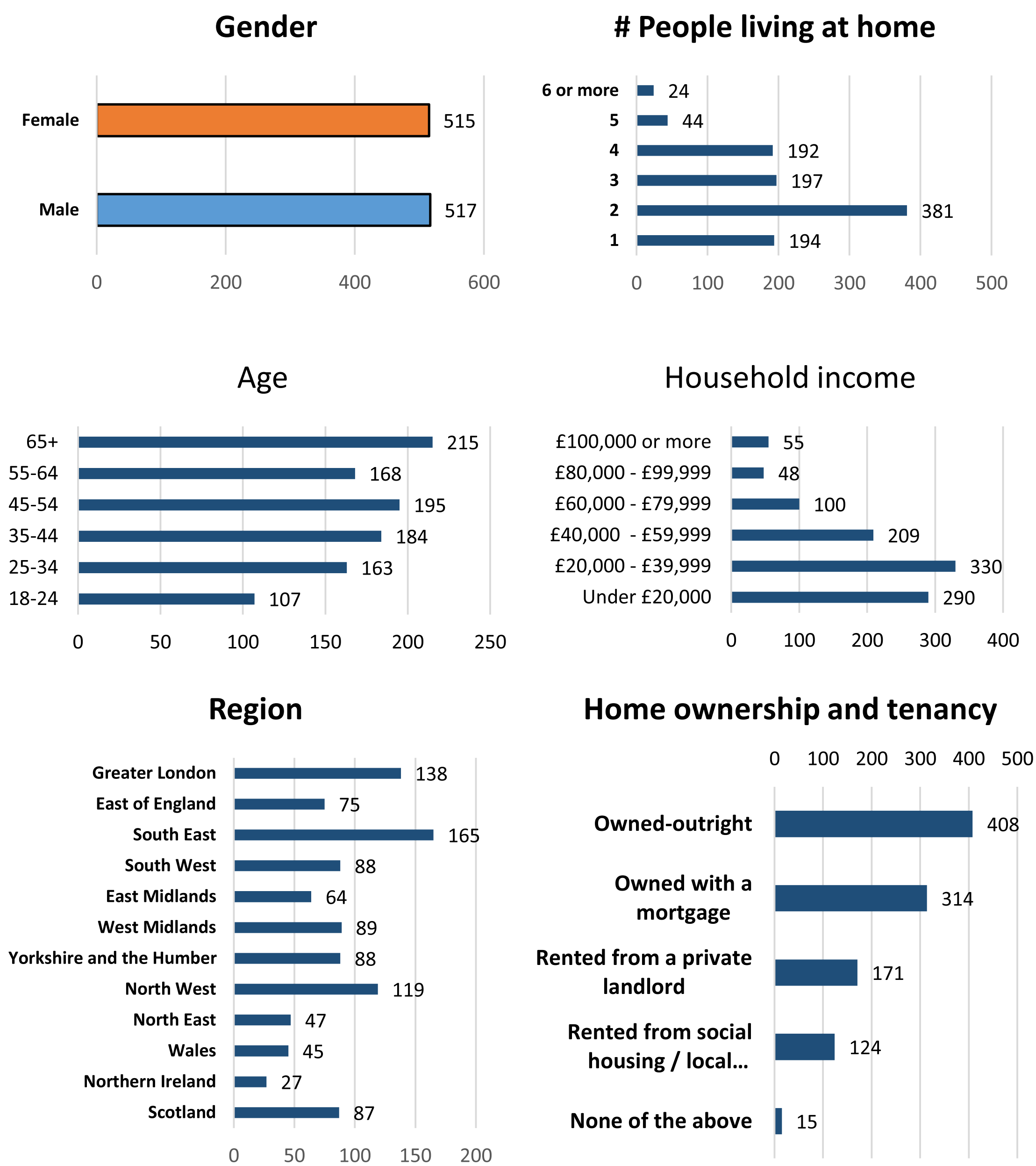

Fig. 2. Demographic details of smart home technology survey respondents in the UK (n = 1032).
Source: Authors.

4. Results and discussion: Knowledge, sustainability, and vulnerability

Both our survey and focus groups resulted in a rich collection of data about the social dynamics and demographics of smart homes. Looking across a high-level summary of all survey questions (see Table 2), most people within our sample have an idea of what SHTs are. Generally, people trust SHT companies and suppliers more than they trust government or even academic institutions and scientists. People do think that SHTs will increase dependency on technology and experts. Most people also think that SHTs can reveal sensitive data and are an invasion of privacy. Here, we organize a deeper discussion of our results inductively by the core themes mentioned in our literature review above: knowledge, adoption, and emotions; energy practices and sustainability; and vulnerability and exclusion.

4.1. Knowledge, adoption, and emotions

To examine knowledge vs. ignorance of SHTs, we first examined our survey data by creating two different sets of groups: those considered knowledgeable vs. those who considered themselves less knowledgeable[f], as well as those who have adopted SHTs compared to those that

[f] In our survey, we posed the question: ‘How much would you say you know about smart home technologies? Answers to this question were ranked from 1 to 4 (1 = Nothing at all, I have no idea what they are, to 4 = I have a very good idea of what they are). Based on respondents’ answers, we created the following two knowledge groups for comparison: “Little knowledge” of SHTs included those who answered that they either knew nothing of SHTs or had a vague idea of what SHTs are (N = 466); and “Good knowledge” of SHTs which included those who answered that they had either a good or a very good idea of what SHTs are (N = 566).

Table 1
Demographic attributes of focus groups in London, Manchester, and surrey (n = 18).

Age	Gender	Ethnicity
Focus Group 1 London (urban)		
Age	Gender	Ethnicity
18	Female	White and Black African
21	Female	Chinese
24	Female	White and Asian
54	Female	British
56	Male	Any other ethnic group
62	Male	British
73	Male	British
Focus Group 2 Greater Manchester (Rural)		
Age	**Gender**	**Ethnicity**
66	Male	British
65	Male	British
73	Male	British
59	Female	British
Focus Group 3 Surrey (Rural)		
Age	**Gender**	**Ethnicity**
21	Male	British
29	Male	British
33	Male	British
40	Female	Any other Mixed/Multiple ethnic background
49	Female	British
52	Male	Arab
58	Male	British

Source: Authors.

have not[g]. In both instances, statistically significant differences in perceptions and preferences emerge concerning three aspects of the survey: knowledge, emotions, and trust.

For the first group, Mann Whitney U tests were run to determine whether those who have *little knowledge* and those who have *good knowledge* of SHTs had similar perceptions of the *main purpose of SHTs* (see Fig. 3). There were statistically significant differences in the two knowledge groups in regards to their perceptions of the purposes of SHTs. Those with good knowledge of SHT's responded significantly higher to the purpose of SHTs being to enhance entertainment (U = 85195.5, z = −7.348, p < .05), make life at home more convenient (U = 100010.5, z = −5.446, p < .05), control smart appliances (U = 104487.5, z = −4.000, p < .05), enhance communication (U = 85076, z = −7.251, p < .05), support assisted living (U = 92266, z = −4.063, p < .05), and manage home security (U = 107081.5, z = −3.548, p < .05). The effect size for these analyses was found to be within Cohen's convention for a small effect (0.20 < d < 0.50). Those with good knowledge also responded higher to the purpose of SHTs being to manage energy use and heat (U = 111069.5, z = −2.389, p < .05) and monitor family members (U = 97396.5, z = −2.304, p < .05), to which the good knowledge group also responded significantly higher. The findings for these tests were within trivial effect size (d < .20).

The claims in particular about supporting assisted living are apt, as they also emerged out of our focus group and open-ended survey data. As one respondent said:

LM: *People with disabilities can benefit, even if they have a problem for leaving their home. With smart home technologies, they can interact with the rest of the world because they are networked up and have a smart assistant to work as their PA.*

This hints at the ability for SHTs to end social isolation. Another noted that:

LF: *Because of disabilities some people could find them very useful. They might not be able to get out and do the shopping which others might do on the way home and don't have the same social connections.*

This also sees SHTs as socially empowering. A focus group member from London acknowledged this feature when he noted that:

LM: *Increasingly the old frail, if the technology is, you know, tailored to their needs, it means they can stay at home longer, and that means they won't need to go into care homes, and that's going to be an enormous saving for society and for individuals.*

In addition, Mann Whitney U tests were run to determine whether those who have *little knowledge* and those who have *good knowledge* of SHTs had similar perceptions of the *potential benefits of SHTs*. Again, there were statistically significant differences in the two knowledge groups in regards to their perceptions of the potential benefits of SHTs being to: save time (U = 96388.5, z = −6.053, p < .05), save money (U = 103936.5, z = −3.679, p < .05), enhance leisure (U = 92761.5, z = −6.016, p < .05), provide comfort (U = 92696, z = −5.953, p < .05), provide care (U = 95034, z = −3.695, p < .05), improve quality of life (U = 92237, z = −6.045, p < .05), make life easier (U = 91779.5, z = −7.528, p < .05), improve security (U = 103723, z = −4.217, p < .05), and save energy (U = 108343.5, z = −3.319, p < .05), for which those with good knowledge of SHT's responded higher. The effect sizes for these analyses were found to be within Cohen's convention for a small effect size (0.20 < d < 0.50). The good knowledge group also responded significantly higher to the benefits of SHTs being to save the environment (U = 105241.5, z = −2.566, p < .05). This effect size was trivial (d < 0.20).

We also asked respondents how SHTs made them feel (see Fig. 4). A Chi-square test of independence was performed to examine the relation between knowledge of SHTs and respondents' feelings related to SHTs. There was a significant association between knowledge and how SHTs made respondents feel. Those with good knowledge were significantly more likely to say that SHTs made them feel safe (X (1, N = 1032) = 40.049, p < .05)) and empowered/in control of the house (X (1, N = 1032) = 40.516, p < .05)). The effect sizes for these findings, Cramer's V, were weak (V < 0.25). Those with good knowledge of SHTs also we significantly more likely to say that SHTs made them feel protected (X (1, N = 1000) = 20.728, p < .05)), whereas those with little knowledge were more likely to say that SHTs made them feel none of the options given (X (1, N = 1032) = 6.262, p < .05)). The effect sizes for these findings, Cramer's V, were weak (V < 0.25). There was no statistically significant relation between knowledge and SHTs making respondents feel dependent on technologies, lazy, exposed, unsafe, ambivalent or other.

These results—and the tensions between those who see benefits compared to risks of SHT adoption—also emerged from our open-ended survey questions and the more qualitative focus groups. On the one hand, a class of respondents mentioned how SHTs enhance the ability for homes to be protected, secure, and safe. R66 stated that "*I caught a burglar in my home on Canary camera but police still don't have any one arrested as yet,*" R888 that "*I have a video doorbell and it makes the household more secure,*" and R943 that "*Smart cameras are useful to monitor pets and what they are up too when away from home.*"

However, others mentioned how SHTs led to greater fear and anxiety. As one put it: "*Alexa is listening all the time. Alexa is monitoring conversations, we deliberately talked about cat food around her, and soon cat food advertising appeared predominantly which was never there before, so they are monitoring and using our data for their own ends and advertising.*" Another noted that "*Sometimes couples use [SHTs] to spy on each other.*"

We lastly examined whether adopters of SHTs had substantially different preferences than non-adopters. Mann Whitney U tests were run

[g] Two groups were created according to their level of adoption of SHTs. We posed the question: Do you own or use any smart home technologies? If so, how many? to which respondents were able to input relevant values, creating a continuous variable. We created the following two adoption level groups for comparison: "Non adopters" of SHTs included those who answered that they had zero SHTs (N = 398); and "SHT adopters" included those who responded that they had 1 or more SHTs (N = 634).

Table 2
Descriptive statistics and summary of smart homes survey results (N = 1032).

Questions		All respondents (N=1,032) mean or count	SHT adopters		Knowledge		Age		Income		Tenancy	
			Non-adopters (N=398)	Adopters (N=634)	Little (N=466)	Good (N=566)	Young (N=122)	Old (N=215)	Low (N=325)	High (N=297)	Home-owners (N=408)	Social renters (N=124)
The main purposes of smart home technologies are**	Enhance entertainment	3.75	3.39	3.96	3.52	3.93	4.01	3.41	3.57	3.84	3.56	3.80
	Make life at home more convenient	4.14	3.87	4.29	3.99	4.25	4.34	3.88	3.99	4.24	3.97	4.15
	Control smart appliances	4.13	4.02	4.20	4.05	4.20	4.08	4.05	4.00	4.17	4.11	4.13
	Monitor family members	2.91	2.77	2.99	2.80	2.99	3.09	2.29	2.86	2.96	2.65	2.97
	Manage energy use and heat	4.13	3.99	4.20	4.07	4.17	4.08	4.02	4.09	4.14	4.10	4.22
	Enhance communication	3.73	3.46	3.89	3.49	3.92	3.83	3.46	3.68	3.71	3.62	3.72
	Support assisted living or health	3.68	3.56	3.75	3.55	3.78	3.84	3.38	3.66	3.71	3.58	3.72
	Manage home security and safety	4.07	3.99	4.12	3.99	4.14	4.13	4.01	3.94	4.10	4.06	3.97
The potential benefits of smart home technologies are to**	Save time	3.88	3.59	4.05	3.69	4.02	4.15	3.47	3.72	3.95	3.66	4.08
	Save money	3.66	3.37	3.84	3.53	3.77	3.67	3.41	3.56	3.66	3.57	3.70
	Save energy	3.94	3.69	4.08	3.83	4.02	4.03	3.67	3.82	3.95	3.79	4.13
	Save the environment	3.58	3.28	3.75	3.48	3.65	3.64	3.27	3.48	3.62	3.45	3.71
	Enhance leisure	3.77	3.45	3.95	3.57	3.91	4.10	3.39	3.55	3.82	3.61	3.75
	Provide comfort	3.72	3.47	3.87	3.52	3.87	4.00	3.40	3.58	3.81	3.59	3.69
	Improve security	4.01	3.87	4.10	3.89	4.10	4.12	3.91	3.87	4.00	3.96	4.04
	Provide care	3.47	3.26	3.58	3.34	3.57	3.65	3.14	3.37	3.48	3.40	3.38
	Improve quality of life	3.61	3.26	3.82	3.40	3.77	3.82	3.22	3.44	3.70	3.47	3.54
	Increase property value	3.14	2.93	3.25	3.06	3.20	3.51	2.83	3.11	3.10	3.05	3.09
	Make life easier	3.94	3.61	4.15	3.71	4.13	4.24	3.66	3.75	4.01	3.78	3.94

Smart home technology makes me feel overall*	Safe	328	63	265	101	227	55	45	91	95	116	42
	Unsafe	123	70	56	68	58	17	32	47	29	61	11
	Empowered/In control of the house	267	49	218	76	191	43	40	58	89	103	24
	Dependent on technologies	326	146	180	154	172	38	75	95	91	138	35
	Lazy	204	89	115	92	112	27	39	59	55	67	33
	Ambivalent	121	55	66	65	56	5	33	34	40	64	6
	Other	22	14	8	15	7	1	4	11	6	8	4
	None of these	124	62	62	69	55	12	30	49	31	41	18
	Exposed	182	96	86	92	90	22	39	68	44	79	19
	Protected	177	27	150	53	124	21	30	47	56	64	26
There is a risk that smart home technologies**	Increase dependency on technology	4.05	4.10	4.03	4.05	4.06	4.02	4.04	4.02	4.03	4.06	4.10
	Increase dependency on electricity networks	3.98	4.00	3.97	3.96	3.99	3.97	4.02	3.94	3.98	4.04	3.98
	Increase dependency on outside experts	3.75	3.81	3.72	3.77	3.74	3.67	3.83	3.75	3.64	3.84	3.63
	Result in a loss of control	3.62	3.82	3.51	3.72	3.54	3.52	3.63	3.64	3.64	3.72	3.50
	Disrupt daily routines	3.26	3.33	3.23	3.32	3.22	3.29	3.12	3.39	3.22	3.19	3.30
	Make household members lazy	3.80	3.96	3.70	3.93	3.69	3.81	3.70	3.82	3.74	3.75	3.92
	Are intrusive	3.70	3.87	3.60	3.79	3.63	3.72	3.62	3.79	3.63	3.72	3.72
	Reveal sensitive data	3.81	3.96	3.72	3.87	3.76	3.72	3.84	3.85	3.92	3.89	3.75
	Are an invasion of privacy	3.73	3.93	3.61	3.79	3.69	3.60	3.75	3.79	3.74	3.80	3.69
	Are non-essential luxuries	3.94	4.16	3.81	4.06	3.85	3.99	3.95	4.04	3.81	3.96	4.06
	Make households worry more	3.30	3.46	3.22	3.42	3.22	3.25	3.32	3.35	3.25	3.39	3.26
	Waste household income and money	3.38	3.65	3.22	3.51	3.29	3.41	3.44	3.41	3.35	3.45	3.34

Notes:
Mean values from answers to Likert type questions (1 = Strongly disagree to 5 = Strongly agree), “Don’t knows” have been reported as missing values. Count is frequency to those selecting yes to a yes/no question.
SHT adopters and Knowledge groups were tested on purpose, benefits and feelings related to smart home technologies (SHTs).
Age, Income and Tenancy groups were tested on risks related to SHTs.
Color/shading indicates significant at $p < .05$.
Benjamini-Hochberg Procedure was used post hoc for the correction of multiple comparisons.
*Chi-square test.
**Mann Whitney *U* test.
Source: Authors.

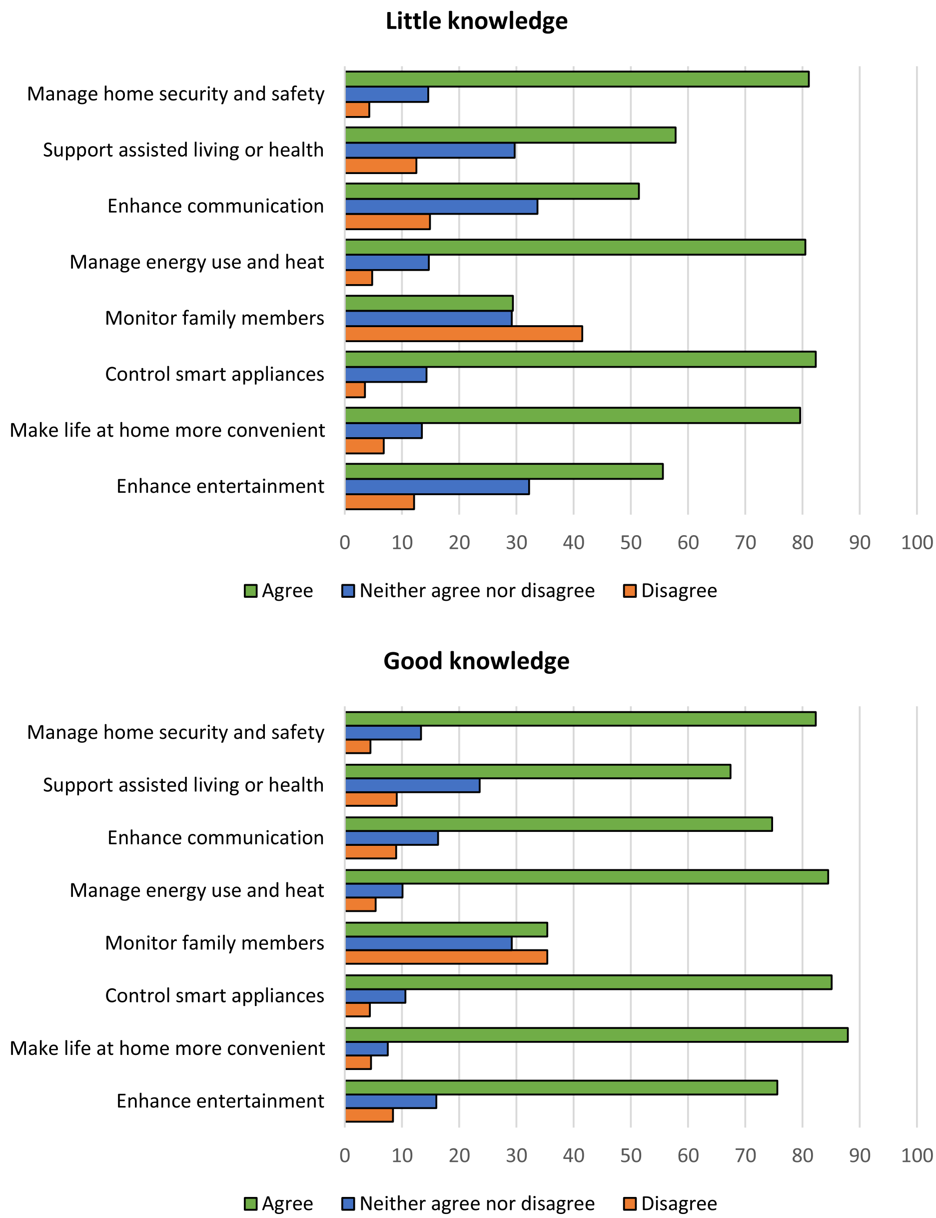

Fig. 3. The main purpose of smart home technologies classified by degree of knowledge and familiarity about them.
Source: Authors, from valid responses in Little knowledge and Good knowledge groups; total N = 1032: Little knowledge N = 466, Good knowledge N = 566.

to determine whether those *non adopters* and *SHT adopters* had similar perceptions of the *main purpose of SHTs*. There were statistically significant differences in the two adoption groups in regards to their perceptions on the following purposes of SHTs: enhancing entertainment (U = 72388.5 z = −9.300, p < .05), for which adopters of SHT responded significantly higher. This effect exceeded Cohen's convention for a medium effect (*d* = 0.62). SHT adopters responded significantly higher also to SHTs purpose being to make life at home more convenient (U = 85761.5, z = −7.540, p < .05), control smart appliances (U = 99618.5, z = −3.852, p < .05), manage energy use and heat (U = 98345, z = −4.111, p < .05), and enhance communication (U = 83841, z = −6.248, p < .05), for which effect sizes were small (0.20 <*d* < 0.50). In terms of SHT purposes being to monitor family members (U = 91051.5, z = −2.458, p < .05), support assisted living (U = 92346, z = −2.684, p < .05), and manage home security (U = 105741, z = −2.535, p < .05), SHT adopters again responded significantly higher. The Cohen d effect sizes for these were found to be trivial (d < 0.20).

Similar results occurred over the perceptions of benefits. Mann Whitney U tests were run to determine whether those *non adopters* and *SHT adopters* had similar perceptions of the *main benefits of SHTs*. There were statistically significant differences in the two knowledge groups in regards to their perceptions of the potential benefits of SHTs. Those who had adopted SHT's responded significantly higher to SHTs potentially enhancing leisure (U = 81081, z = −7695, p < .05), improving quality of life (U = 79007, z = −7.957, p < .05) and making life easier (U = 82819, z = −8.468, p < .05). These analyses exceeded Cohen's convention for a medium effect (*d* > 0.50). SHT adopters also responded higher to SHTs potential benefits being to save time (U = 86499.5, z = −7.234, p < .05), save money (U = 8667, z = −6.430, p < .05), save energy (U = 91498.5, z = −5.993, p < .05), save the environment (U = 83480.5, z = −6.464, p < .05), provide comfort (U = 88208.5, z = −5.739, p < .05), improve security (U = 102107.5, z = −3.209, p < .05), provide care (U = 86230, z = −4.484, p < .05), and increase property value (U = 89009.5, z = −4.138, p < .05). These analyses were found to have small effect sizes (Cohen *d* 0.20 < *d* < 0.50).

Finally, similar themes emerged concerning the differences in

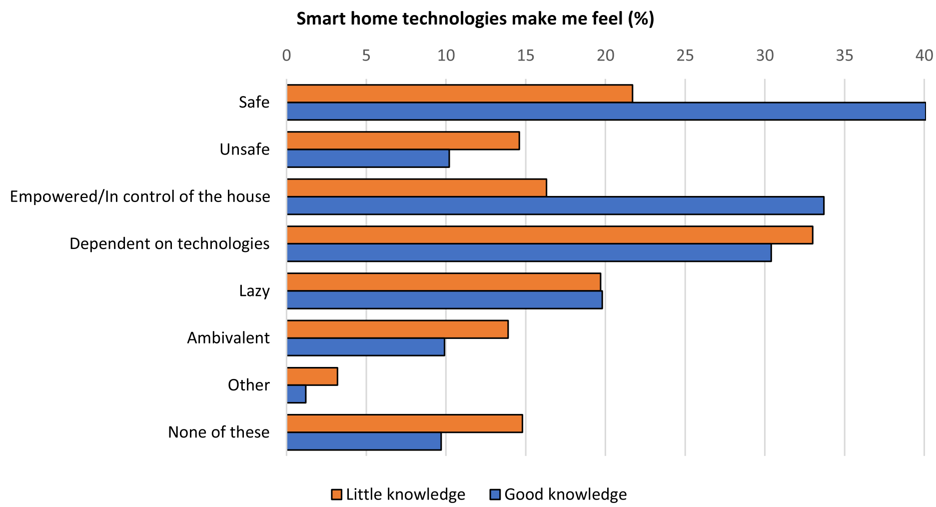

Fig. 4. The emotions of smart home technologies classified by degree of knowledge and familiarity about them.
Source: Authors, from valid survey respondents who answered yes (total N = 1032: Little knowledge N = 466, Good knowledge N = 566).

emotions between adopters and non-adopters (See Fig. 5). A chi-square test of independence was performed to examine the relation between the level of adoption and feelings related to SHTs. There was a significant association between adoption level and how SHTs made respondents feel. SHT adopters were significantly more likely to say that SHTs made them feel safe (X (1, N = 1032) = 76.053, p < .05)). The effect size for this finding, Cramer's V, was moderate (V = 0.27). SHT adopters were also significantly more likely to say that SHTs made them feel empowered/in control of the house (X (1, N = 1032) = 62.117, p < .05)). The effect size for this finding, Cramer's V, was weak (V = 0.24). Non-adopters were significantly more likely to say SHTs made them feel dependent on technologies (X (1, N = 1032) = 7.780, p < .05)), unsafe (X (1, N = 1032) = 17.486, p < .05) or other (X (1, N = 1032) = 5.963, p < .05)). The effect sizes for these findings, Cramer's V, were weak (V < 0.25). SHT adopters were significantly more likely to say that SHTs made them feel protected (X (1, N = 1000) = 45.771, p < .05)), while non-adopters were significantly more likely to say that SHTs made them feel exposed (X (1, N = 1000) = 21.758, p < .05)). The effect sizes for these findings, Cramer's V, were weak (V < 0.25). There was no statistically significant relation between adoption and SHTs making respondents feel lazy (X (1, N = 1032) = 2.749, p = .097)) or ambivalent (X (1, N = 1032) = 2.745, p = .098)).

4.2. *Energy practices, consumption and sustainability*

Our second core cluster of results center on the theme of energy practices, consumption, and whether smart homes encourage or complicate efforts at sustainability. Here, we intentionally designed our questions to examine the extent that smart homes would encourage domestic practices related to utility or leisure, and sustainability or waste.

To contextualize our findings within the literature in our survey, we drew from a typology of smart home functions and uses. According to Drum (2017), economists generally break employment into cognitive versus physical jobs and routine versus nonroutine jobs. This gives us four basic categories of work:

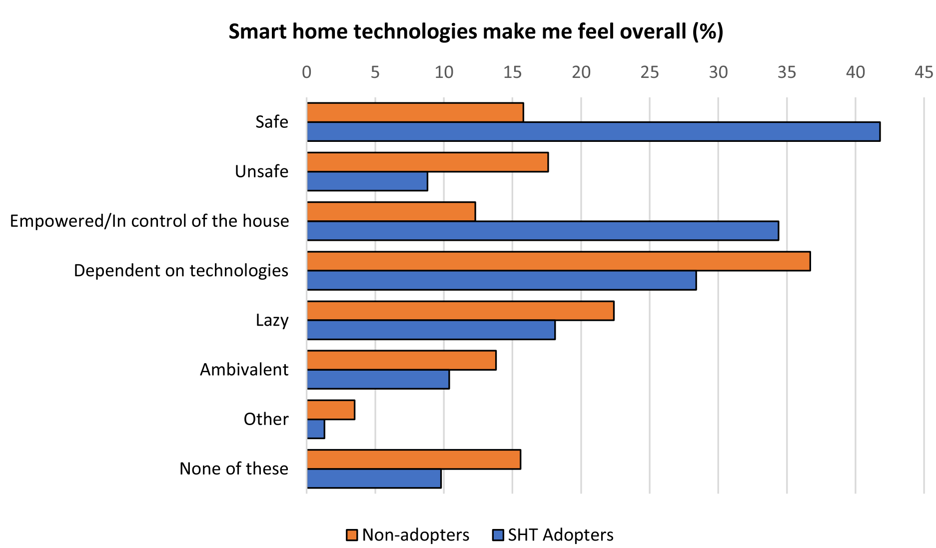

Fig. 5. The emotions of smart home technologies classified by adopters and non-adopters.
Source: Authors, from valid survey respondents who answered yes (total N = 1032: Non-adopters N = 398, SHT Adopters N = 634).

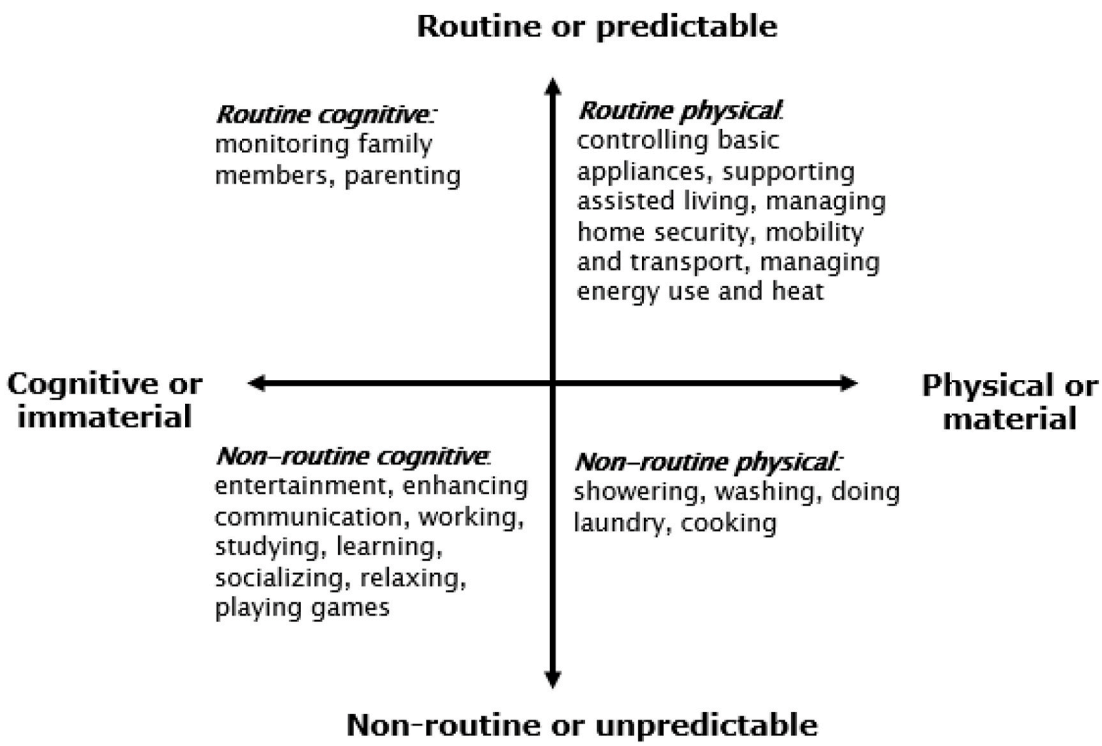

Fig. 6. A typology of smart home technological tasks and functions.
Source: Authors.

- Routine physical: digging ditches, driving trucks
- Routine cognitive: accounts-payable clerk, telephone sales
- Nonroutine physical: short-order cook, home health aide
- Nonroutine cognitive: teacher, doctor, CEO

We adapted this typology of tasks to SHTs in Fig. 6. Routine tasks would be those that tend not to vary throughout the day, non-routine would be those that vary and be less predictable. Physical tasks would relate SHT controlling material things or the environment, cognitive tasks would relate to emotions and experiences. This creates four general classes of functionality for SHTs:

- Routine physical: controlling basic appliances, supporting assisted living, managing home security, mobility and transport, managing energy use and heat
- Routine cognitive: monitoring family members, parenting

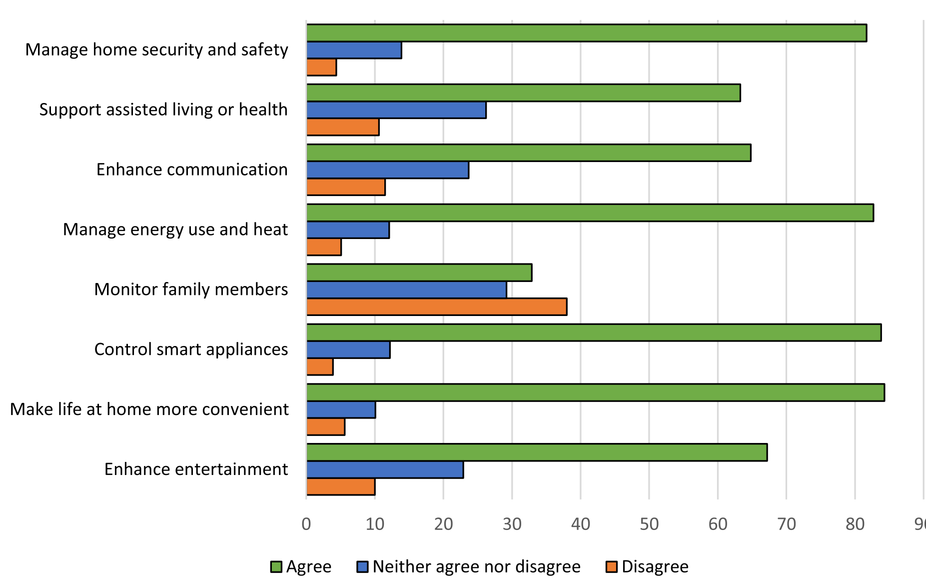

Fig. 7. The main purpose of smart home technologies classified by all respondents.
Source: Authors, from all valid survey responses, excluding "don't know" answers.

Table 3
Survey respondent groups by age, income, and tenancy.

Group	Sub group	Description	N
Age	Young	25 years and younger	122
	Old	65 years and older	215
Income	Low income	Income less than £20,000 per year before income tax	325
	High income	Income more than £50,000 per year before income tax	297
Tenancy	Home owner	Owns a home without mortgage	408
	Social renter	Rents a home from a social housing or local authority sector	124

Source: Authors.

- Non-routine physical: showering, washing, doing laundry, cooking
- Non-routine cognitive: entertainment, enhancing communication, working, studying, learning, socializing, relaxing, playing games

As Fig. 7 indicates, we see all four of these typological tasks preferred within our sample of respondents. Looking across the survey as a whole—all respondents—more than 30% preferred routine cognitive tasks such as monitoring children or family; more than 64% stated they enjoyed the idea that SHTs assist with non-routine cognitive such as playing games or entertainment; 83.8% indicated a preference that they help with routine physical tasks such as controlling appliances; and 84.3% suggested they prefer SHTs to assist with making non-routine physical tasks such as cooking or laundry more convenient.

Many respondents did take the time to actively mention some of the energy or environmental benefits of their SHTs. R67 stated in the survey that "*since we got our smart meter in the kitchen we regularly monitor our energy usage and have made a concerted effort to lower it,*" another (R766) noted that "*we noticed while on holiday our Hive wasn't active - we asked a family member to check, and there had been a power-cut which tripped the breakers. Saved us at least £300 in freezer food.*" In the focus groups too, one participant remarked the sustainability benefits of SHTs:

LM: *A smart fridge telling you that you're running out of milk or your ham it's gone off is very useful, and helps with sustainability. Or you're your washing cycle has finished or planning to do the washing at the most efficient time, electricity wise.*

Another participant articulated how a SHT was saving him money:

> **LM**: *I install a Hive and I saved £15 a month that I have to pay towards my Hive, it actually does save money and I can buy my Hive at £15 a month …. The guy that sold it to me said you can do a deal with British Gas and pay £15 a month. And I've saved that money on utility bills.*

A third remarked the benefits of being able to monitor energy use via

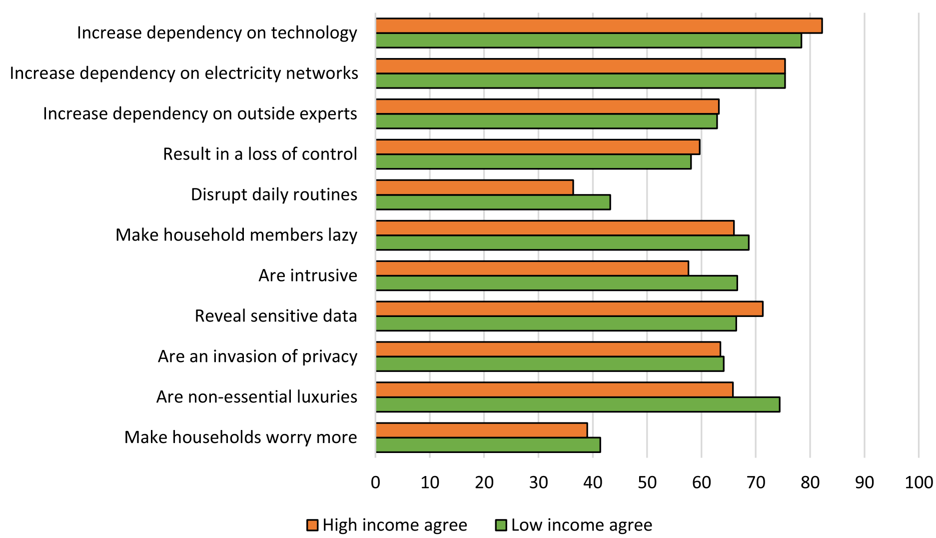

Fig. 8. The perceived risks of smart home technologies classified by income subgroups.
Source: Authors, valid survey responses from those earning £20,000 and less (low income, N = 325)) and those earning £50,000 and more (high income, N = 297).

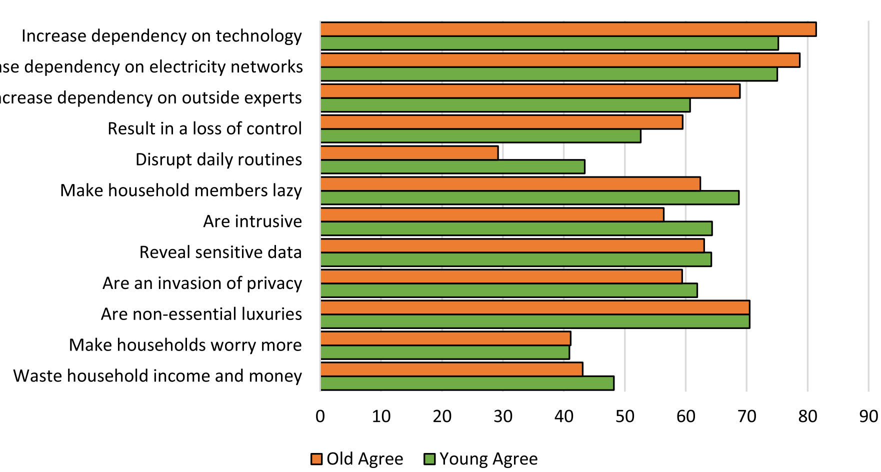

Fig. 9. The perceived risks of smart home technologies classified by age subgroups.
Source: Authors, valid survey responses from young (25 years and younger, N = 122) and old people (65 years and older, N = 215).

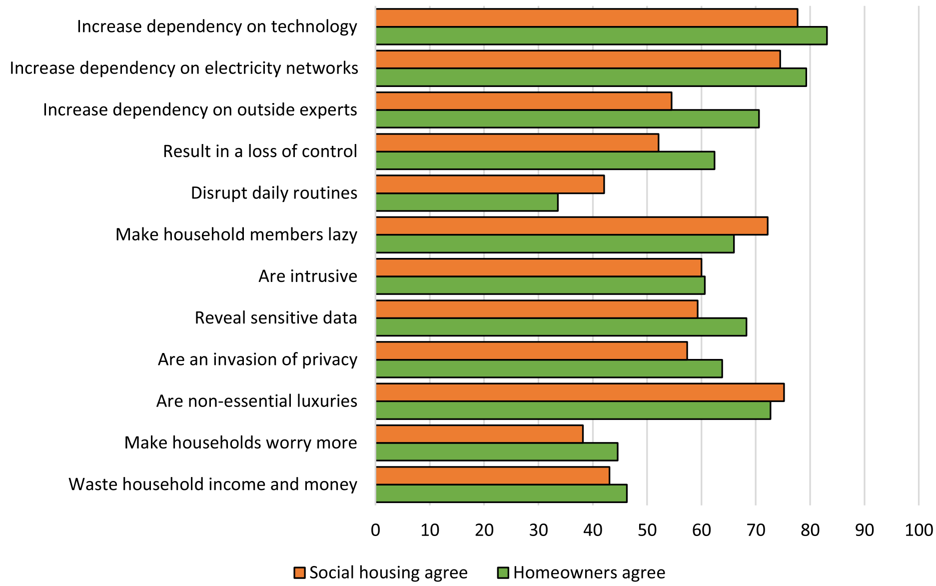

Fig. 10. The perceived risks of smart home technologies classified by age subgroups.
Source: Authors, valid survey responses from those owning their homes outright (homeowners, N = 408)) and those renting from social housing or local authority landlords (social renters, N = 103).

SHTs:

SF: *I think the biggest benefits are monitoring and efficiency. With Nest, for example, you're meant to be more efficient in terms of energy. The same with Hue. You can use less electricity. We've got a lot of spotlights as opposed to having the whole room on. So, that costs us less, and that's obviously one of the things that attracts us to buy these.*

A fourth stated how SHTs help with monitoring energy:

SF: *You could also use [SHTs] to monitor your usage, which then could make you more efficient. We get a report each month from Nest, and it tells us how much we've used in terms of electricity and, my husband is a geek, and he finds it amazingly interesting and wants to beat each month.*

However, these statements did contrast with other respondents who mentioned how SHTs can lead to profligate use of energy, increased waste, and reductions in sustainable practices. R44 joked in the survey that "*My children stopped asking me questions and kept asking Alexa .... they would change my music and I'd end up listening to baby shark over and over,*" not exactly a judicious use of resources in terms of sustainability. Others patently noted their intent to use SHTs only for non-energy related, everyday uses, including R887: "*I only use an Echo and Alexa for music*" and "*I use my google home on an everyday basis to check the weather, how to spell words*" and R909: "*I have smart plugs to help with Christmas tree lights, invaluable!!!*" R555 even noted how to them "*Smart technologies are like the butlers you always wanted without actually hiring a butler.*" The focus groups also revealed the primary of SHTs being used for non-energy related, and perhaps even energy wasteful, tasks:

LF: *I use my Amazon Alexa only to find out one of the answers for a quiz. That's the only time we ever keep it on.*

Our results confirm previous research (e.g. Wilson et al., 2015; Sovacool and Furszyfer Del Rio, 2020) which has shown that the purpose and benefits of SHTs can fill multiple needs, ranging from monitoring essential services such as energy use to using SHTs purely for entertainment purposes. What remains unclear though is whether SHTs are used to their full potential in all circumstances, and even though many of our focus group members noted the benefits on energy monitoring, for example, whether SHTs' reduce overall household energy consumption.

LM: *I can tell my Alexa what music to play from the 1950s, and, you know, that's good.*

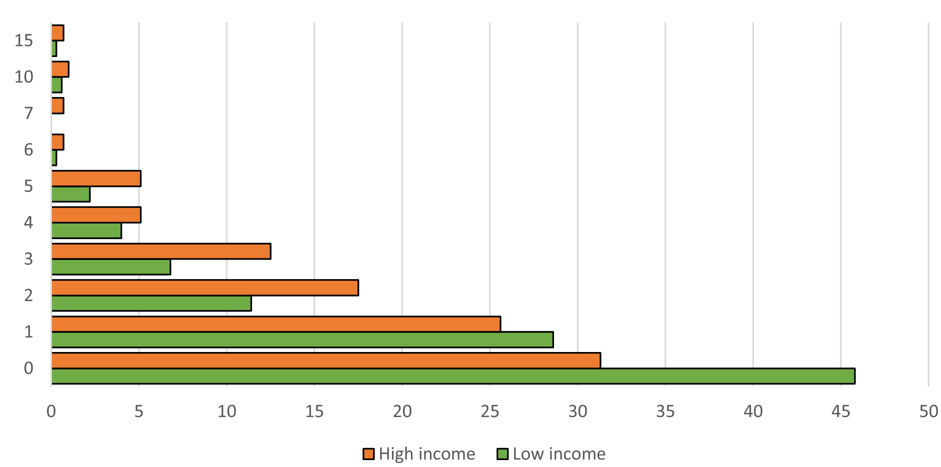

Fig. 11. Number of smart home technologies respondents (%) own or use.
Source: Authors.

4.3. Vulnerability, deskilling and exclusion within subgroups

Our final theme of analysis investigates who, if anyone, may be left behind by SHTs, or at least placed into greater aspects of vulnerability. We also included data on themes related to skills, jobs, reliability, and dependence into this category of analysis.

We started by intuitively breaking our survey respondents into three different categories that we expected would experience smart home risks differently: old adults versus youth (age), wealthy versus poor (income), and homeowners versus those in social housing (tenancy). Table 3 offers an overview of these three subgroups of respondents, with data used from the Office for National Statistics (2019) to create our categories.

We posed the question on the potential risks of SHTs (see Fig. 8) and ran a Mann Whitney U tests to determine whether those on *low incomes* and those on *high incomes* had similar perceptions of the *risks related to SHTs*. There were statistically significant differences in the two income groups in regards to their perceptions of the risk of SHTs being non-essential luxuries (U = 38485.5, z = −3.005, p < .05), to which low income groups answered higher. This finding had a small effect size (Cohen's $d = 0.24$).

There were statistically no differences between the income groups saying that there were risks that SHTs would disrupt daily routines (U = 37775, z = −2.069, p < .05); be intrusive (U = 38775.5, z = −2.243, p < .05), increase dependency on technology (U = 44894.5, z = −0.187, p = .852); increase dependency on electricity networks (U = 40149, z = −0.771, p = .44); increase dependency on outside experts (U = 39613.5, z = −0.603, p = .547); result in a loss of control (U = 42464.5, z = −0.065, p = .948); make household members lazy (U = 40119, z = −1.357, p = .175); reveal sensitive data (U = 37794, z = −0.679, p = .497); are an invasion of privacy (U = 41878, z = −0.517, p = .605); make households worry more (U = 36809, z = −1.081, p = .28); or waste household income and money (U = 39577, z = −0.907, p = .364). The effect sizes for these analyses were found to be trivial (Cohen's $d < 0.20$).

In terms of our two subgroups for age, we posed the question on the potential risks of SHTs (see Fig. 9) and ran a Mann Whitney U tests to determine whether *young* and *old* respondents had similar perceptions of the *risks related to SHTs*. There were statistically no differences between the age groups saying that there were risks that SHTs would increase dependency on technology (U = 11393, z = −0.807, p = .42); increase dependency on electricity networks (U = 10768, z = −0.379, p = .705); increase dependency on outside experts (U = 10241, z = −0.811, p = .418); result in a loss of control (U = 10458, z = −1.012, p = .312); disrupt daily routines (U = 9700, z = −1.324, p = .185); make household members lazy (U = 10429.5, z = −1.223, p = .221); are intrusive (U = 10143, z = −1.084, p = .278); reveal sensitive data (U = 9442.5, z = −0.472, p = .637); are an invasion of privacy (U = 10570.5, z = −0.768, p = .442); are non-essential luxuries (U = 11314.5, z = −0.372, p = .71); make households worry more (U = 9613, z = −0.43, p = .667); and waste household income and money (U = 11055.5, z = −0.082, p = .935). The effect sizes for these analyses were found to be trivial (Cohen's $d < 0.20$).

Lastly, in terms of housing tenancy, we posed the question on the potential risks of SHTs (see Fig. 10) and ran a Mann Whitney U tests to determine whether *homeowners* and *social housing* occupants had similar perceptions of the *risks related to SHTs*. There were no statistically significant differences between the two tenancy groups in relation to SHTs potentially having the following risks: increase dependency on outside experts (U = 18640.5, z = −2.045, p < .05), make household members lazy (U = 19526, z = −2.18, p < .05), increase dependency on technology (U = 22402, z = −1.27, p = .204); increase dependency on electricity networks (U = 21372, z = −0.504, p = .615); result in a loss of control (U = 19781, z = −1.812, p = .07); disrupt daily routines (U = 19736, z = −1.177, p = .239); are intrusive (U = 21971, z = −0.04, p = .968); reveal sensitive data (U = 18784.5, z = −1.421, p = .155); are an invasion of privacy (U = 20899.5, z = −0.907, p = .364); are non-essential luxuries (U = 21493.5, z = −1.256, p = .209); make households worry more (U = 17336.5, z = −1.02, p = .308); and waste household income and money (U = 19679.5, z = −0.906, p = .365). The effect sizes for these analyses were found to be trivial (Cohen's $d < 0.20$).

In a nutshell, our findings show that in terms of perceptions there was little statistically significant differences between income (affluent versus poor), housing tenancy (homeowners versus social housing) and age (young versus old). Nevertheless, the possibility of SHTs to exclude particular groups did arise in our focus groups, with an example from two participants saying that income played a part:

LM: *Smart home technologies are clearly aimed at geeks, and the wealthy, who will always find and make up uses for them.*

LF: *So, [SHTs] are almost like a status symbol, it's like in college, some people are like, 'Oh, I have an Alexa.' And other people are like, 'I'm not rich enough to have that.*

Similar themes emerged from the end of our focus groups, when we asked respondents who SHTs were for. Many of their answers imply that SHTs were aimed at people with money (LF), those naturally interested in technology (LM), and those who may have limited time (MM) such as busy professionals (MF). Three participants in particular said that SHTs are not aimed at those on low-incomes (MM, SF), with one adding that "*they may not be able to afford the luxury*" (MM). SM was even pithier by saying, "*poor people are definitely excluded.*" Implicit, or even explicit here, is that SHTs exclude those who are not technically savvy and those who are not affluent. This was similarly indicated by our survey results which showed that 45.8% of the low income group said that they used or owned zero SHTs, compared to 31.3% of the high income group (See Fig. 11). Similarly of those living in social housing, 45.2% said they used or owned zeros SHTs, compared to 43.1% of homeowners. Lastly, in our age groups, 27.9% of young people used or owned zero SHTs, compared to 49.8% of the old age group.

Others discussed SHTs in terms of skills, or the lack of them. One older participant said that he felt disadvantaged as he did not have the technical skills needed, and relied for example on his grandchildren to explain technology (but also then jokingly spoke about them taking control of his hearing aid) (LM). Another participant thought that technology was, on the other hand, also deskilling younger people who were now relying on automatic spellchecks for example (MF):

LM: *I am clearly disadvantaged by SHTs because I become dependent on others such as my grandchild to explain some of the technology to me, which is empowering for the grandchild, but it puts me at a disadvantage. He took control of my hearing aids the other day, which was not good.*

MF: *Smart technologies are deskilling people. The youngsters are well into this, they can't even do their proper mental arithmetic … spellcheck that annoys the heck out of me, people can't spell, they just rely on spellcheck.*

Others mentioned that SHTs could lead to increasing vulnerability in the form of a "*digital divide, those without internet access are excluded*" (SM). However, even for those with internet access, there are risks associated of them becoming too dependent on that particular access, with one participant saying that their home, which has quite a lot of SHTs, was vulnerable when the internet was down, as "*the whole house comes to a standstill … we're dependent on smart to have our home run*" (SF). Another participant was genuinely concerned about cyber-attacks from terrorists, saying that smart buildings (rather than smart homes), such as hospitals, could be at risk (LM).

SF: *We've got quite a lot of smart home tech. My husband's a bit obsessed. So, when the Internet's down the whole house comes to a standstill. Like, all our lights are Hue, and when the power's out, that's it. The house is, like, you know, like Blackpool illuminations. We're dependent on smart to have our home run.*

Another more seriously mentioned the ability for SHTs to heighten vulnerability:

> **LM**: *What I am afraid of is a cyber-attack from a terrorist, or, you know, an enemy nation, or a flare from the sun, that suddenly puts all the electronics out of business, we could be in trouble there. I think you're*

> *probably fairly safe with a smart home, but if you've got smart buildings, what happens then? Where, physically your whole environment is controlled by a third digital partner … Hospitals are going that way and it will move down to individuals, like block of flats.*

This theme of skills and learning was also mentioned in the qualitative part of our survey, when we asked respondents an open-ended question about whether they had a compelling anecdote or story they could tell about SHTs. Multiple respondents mentioned difficulty in learning about, setting up, using, or repairing SHTs. For example, R131 wrote that their "*Smart radiator stopped working, no heat in house!!!*". R336 had bought smart lighting but it did not connect to their Wi-Fi. R678 reflected on how technology was causing problems: "*Technology is a pain because when it breaks you have to go through the drama and pain of remembering passwords etc.*". R899 and R901, both said that SHTs were "*incredibly complex*" to set up.

In line with our findings that smart home risks are not differentiated strongly by age—the young and the old may view them as equally empowering—there was evidence from our focus group data that SHTs could help older people, especially related to monitoring health issues such as irritable bowels, and even saving doctors' time as a result: "*So a smart toilet, if you've got a history of irritable bowel or something like that, then that's one way it can be monitored without you having to go to the doctor, or go to hospital*" (MM). SF reflected on health monitoring too, giving an example of a diabetic friend who was using a smart skin patch that could be scanned using a mobile phone to read blood sugar levels. Or diabetes:

> **SF:** *A friend is diabetic and she now has a smart patch, so instead of taking her blood sugar on her finger, she scans herself with her phone, and then she gets a reading on her blood sugar, and it tells her whether it's going up or down at that right moment … We joke that she's like a robot. But lots of kids have them now.*

A final point about vulnerability that arose from our data—not via the survey, which was more closed ended, but from the focus groups—were global issues connecting smart homes with waste, inefficiency, and environmental destruction. Even though fairly strong regulations such as those in the European Union make it mandatory for all manufacturers and suppliers wishing to sell products consuming electric power to have standby and off modes, our respondents suggested these were not enough to offset inefficient practices and (mis)uses. LM reflected on this by saying how SHTs could be bad for the environment, as people were buying many new SHTs and most would not be able to be upgraded: "*Most of the items are designed to discourage you from repairing them, and most of the perceived wisdom is that you can't repair them, or you're told culturally that you're not to repair it*". SM too said how SHTs could increase waste and the use of materials, with "*plastic and more crap that's going to go to landfill*".

LM: *The built-in obsolescence of all the smart technology we are purchasing, beginning to purchase, is staggering. My wife can, with her five-year-old iPhone, some apps will no longer update. It's horrible for the environment.*

SM: *I don't see how smart technologies could benefit the environment, because actually, you're generating more plastic and more crap that's going to go to landfill.*

SM: *I think there is an environmental damage done, from the rare materials that go into the smart chips to the waste streams.*

These issues all call attention to important "whole systems" issues affecting smart tech that extend well beyond the home or even our country (the UK) of focus (Sovacool et al., 2019, 2020, 2021).

5. Conclusion and policy implications

Smart home technologies (SHTs), despite their fecundity of types and ubiquity of applications in the UK, produce a great range of relations and emotions among respondents. They connect with conflicting practices, some of which help save energy whereas others waste it, confirming some of the findings by Strengers et al. (2020) that albeit portrayed as providing a better quality of life, SHTs do not automatically equal a more sustainable way of life. SHTs also intersect with pressing issues of vulnerability, skills, dependence and exclusion, with potentially empowering attributes for the elderly or those with medical conditions but disempowering attributes for the poor or those who are not technology savvy. With this in mind, we offer three core conclusions.

First, if energy policymakers want to accelerate the adoption of SHTs, our results strongly suggest that knowledge of them leads to greater acceptance and greater likelihood of adoption (see also Wilson et al., 2015). For we found statistically significant differences between those with knowledge of SHTs and those without concerning how positively they viewed the ability for the technology to enhance entertainment, make life more convenient, control smart appliances, better monitor family, enhance communication, support health, and improve home security. Those knowledgeable of SHTs also had statistically significant differences in terms of their perceptions of positive benefits including saving time, saving money, saving energy, saving emissions (the environment), enhancing leisure, enhancing comfort, improving security and overall quality of life. Similarly, those with good knowledge were significantly more likely to say that SHTs made them feel safe, empowered, or in control of the house. Conversely, those with little knowledge were significantly more likely to say that SHTs made them feel unsafe or ambivalent.

Second, if policymakers want to accelerate the adoption of SHTs, experience with them (beyond knowledge), such as actual adoption of some SHT already, has a strong influence on their willingness or desire to buy "more." For there were statistically significant differences between adopters and non-adopters in regards to their perceptions of the positive purposes of SHTs as well as many of their main benefits. Saliently, SHT adopters were significantly more likely to say that SHTs made them feel safe or protected, whereas non-adopters were significantly more likely to say that SHTs made them feel unsafe or exposed.

Thirdly, however, is that if policymakers want to ensure SHTs are sustainable and that adoption does not increase vulnerability, deskilling, and exclusion, then considerable work remains to be done. Our evidence suggests that SHTs are perceived, qualitatively at least, by respondents of the lowest income to disrupt daily routines, be intrusive, and be non-essential luxuries. Those in social housing, also, stated that they believed SHTs would only increase their dependence on outside experts and result in a loss of personal control and autonomy.

The energy sustainability benefits of SHTs, moreover, are not a given, with some respondents mentioning reducing energy consumption or cutting emissions, but others mentioning using SHTs primarily for checking quiz answers, entertainment, playing practical jokes with hearing aids, and turning Christmas lights on—which all arguably use or waste energy. This underscores the need for SHT pathways to be strongly guided by policies, incentives, and regulations to ensure they capture as many of their benefits as possible but also that those benefits are more equitably distributed.

CRediT authorship contribution statement

Benjamin K. Sovacool: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Roles/. **Mari Martiskainen:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Roles/. **Dylan D. Furszyfer Del Rio:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Roles/.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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